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# Gas Hold-Up Profiles Determination by means of Ultrasonic Transducer

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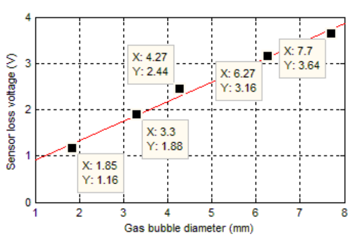
**Graphical abstract**




**Abstract**

This paper details a work carried out to measure gas hold-up profiles in a liquid column using a pair of ultrasonic transducer. The gas hold-up profiles from 1.85 mm to 7.7 mm diameter are of interest in this investigation. The measurement setup consist of ultrasonic transducer, an experimental column, signal conditioning circuit, and a digital storage oscilloscope. The experiment was conducted using several gas hold-up profiles and the relationship between the ultrasonic amplitude and the profile were deduced. A finite element analysis was carried out to further verify the results. This paper explains how one could use ultrasonic transducer to estimate the gas hold-up profiles in a liquid column.

*Keywords*: Gas bubble; ultrasonic transducer; gas measurement



## 1.0 INTRODUCTION

Attenuation in acoustics is known when an acoustic wave travels through a medium, and its energy decreases exponentially with the distance travelled and the energy lost from the radiation appearing as heat. Attenuation is also known as the loss of acoustic energy from a sound beam. Attenuation can be divided into two parts; absorption mechanism that convert acoustic energy into thermal energy and other mechanisms that deflect or scatter acoustic energy out of the beam [1].

The pressure of ultrasonic wave propagating in the medium decreases exponentially along the path as shown in Figure 1 and expressed mathematically in Equation (1):

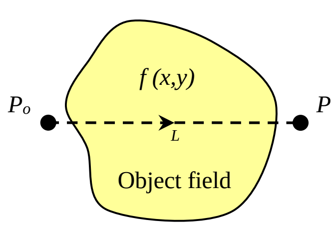



**Figure 1** The ultrasonic attenuation model

$$P = P_o \exp\left(-\int_L f(x,y)dP\right) \tag{1}$$

where
$P$ = the measured sound pressure (dB)
$P_o$ = the initial sound pressure (dB)
$L$ = path length in the object field (m)
$f(x,y)$ = the attenuation function of the object field (dB/m)

It is known that, the pressure is proportional to the voltage measured by the transducer [2] and thus, Equation (1) can be written as Equation (2):

$$v_{Rx} = v_{Tx} e^{-\alpha L} \tag{2}$$

where
$v_{Rx}$ = the ultrasonic receiver voltage (V)
$v_{Tx}$ = the ultrasonic transmitted voltage (V)
$\alpha$ = the attenuation coefficient of the object field (Np/m)

## 2.0 THE SCATTERING EFFECTS

Acoustic impedance is a ratio of acoustic pressure to acoustic volume flow and is a frequency dependent. The greater the difference in acoustic impedance at the interface, the greater will be the amount of energy reflected [3]. At water and gas interface, about 99.94% ultrasonic energy will be reflected [4]. However, in some cases, scattering occurs on small gas hold-ups. Small was define as a sphere with a radius of $a$ where the circumference of the sphere, $2\pi a$, divided by the wavelength $\lambda$ is much less than 1 (i.e. $ka = 2\pi a / \lambda << 1$) where $k$ is the wave number = $2\pi f/c$ [5].

If ultrasonic waves propagate in a bubbly air/water with a wavelength much shorter than the gas radius $a$, i.e. $ka$>>1, the diffraction can be ignored and these hold-ups will act as many acoustics opacities [6]. This is because when $ka$ >>1, the surface of the sphere appears as a flat surface with respect to the wavelength and the scattering becomes the same as reflection from a flat surface [7].

The motivation of the work is to be able to describe the gas hold-up profile (diameter) from the receiving ultrasonic amplitude. The relationship of the simplified ultrasonic transmission model is depicted in Equation (3) and shown graphically in Figure 2.

$$V_G = V_C - V_R \tag{3}$$

where
$V_G$ = sensor loss voltage due to the gas opacity
$V_C$ = calibration voltage
$V_R$ = receiving voltage

In order to estimate the gas hold-up profiles, the parameter $V_G$ is to be resolved.

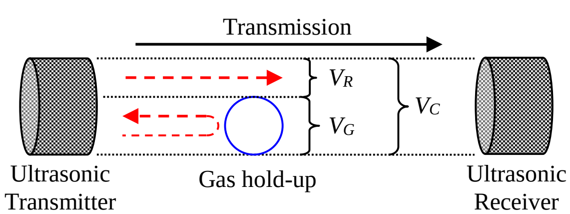



**Figure 2** The simplified ultrasonic transmission model

### 2.1 Finite Element Analysis

The transducer has an active area of 7.1 mm in diameter and radiates 1 MHz ultrasonic wave. The gas hold-up profiles from 1.85 mm to 7.7 mm diameter are of interest in this investigation. There are five samples that have used to represent the gas bubble diameters namely 1.85 mm, 3.3 mm, 4.27 mm, 6.27 mm and 7.7 mm.

The finite element analysis (FEA) was used to observe the response of ultrasonic wave when a gas bubble exists between the transmitter and receiver path as shown in Figure 2. The spatial medium is water and the distance between both transducers is 100mm. The simulated pressure responses on the five samples are shown in Figure 3. The red line represents gas bubble location between the transmitter and the receiver.

It is observed that as the gas diameter increases, the ultrasonic pressure recorded will decrease. To further analyze the relationship between the gas diameter and its sound pressure, an experiment with actual phantom is conducted.

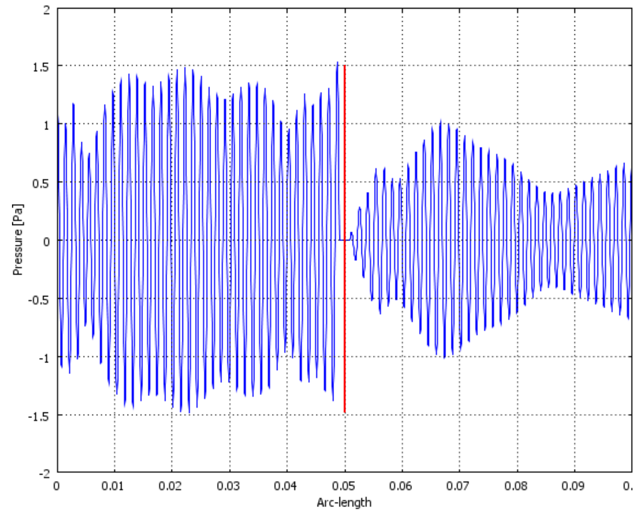



**Figure 3(a)** Gas profile 1.85 mm diameter

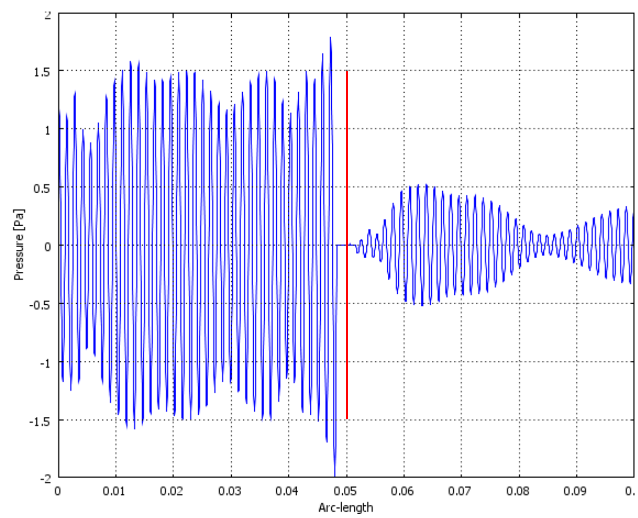



**Figure 3(b)** Gas profile 3.30 mm diameter

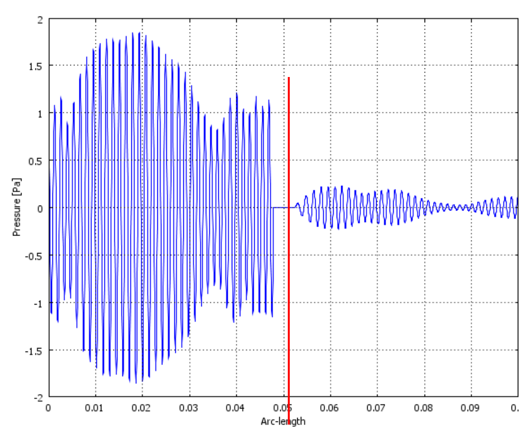



**Figure 3(c)** Gas profile 4.27 mm diameter

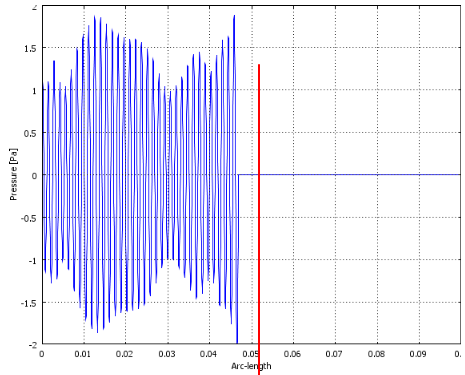



**Figure 3(d)** Gas profile 6.27 mm diameter

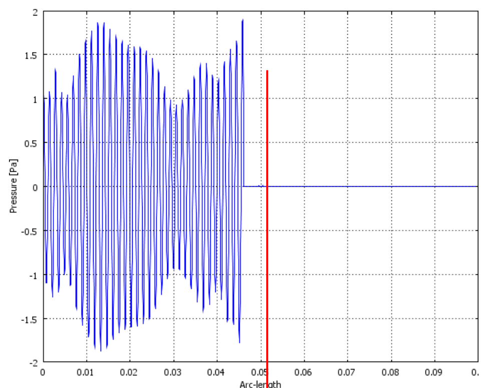



**Figure 3(e)** Gas profile 7.7 mm diameter

## 3.0 EXPERIMENTS AND RESULTS

The experimental setup for evaluating gas hold-up profiles and the ultrasonic receiving signal is shown in Figure 4.

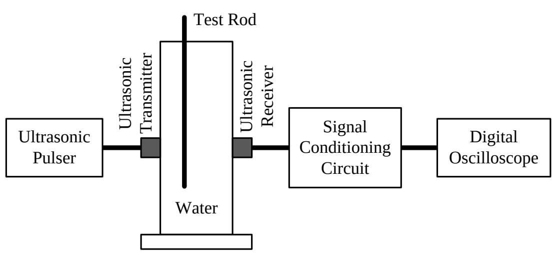



**Figure 4** Experimental setup for measuring the gas hold-up profiles

The selected transducer has an active area of 7.1 mm in diameter and radiates 1 MHz. An ultrasonic pulser was used to generate the ultrasonic pulse tone to the receiver. The transmitter and receiver was clamped on a vertical acrylic column of 100 mm diameter and filled with water. A small amount of gel has been applied on the transducer's surface as an acoustic coupling. The signal conditioning is used to process the receiving signal and the signal amplitude was observed and measured using a digital oscilloscope.

The test rods are hollow and were closed at one end and this will act as gas hold-up which is acoustically opaque. The test rods material is plastic with thickness of 0.1 mm. Before each measurement, a calibration was made by sending a pulse tone to the receiver with empty profile in the column and the receiving signal amplitude was measured. The calibration amplitude will act as initial amplitude.

It is observed that, when the sample was placed in the center of the column, the receiving amplitude decreases proportionally to the sample profiles. The larger the profile, the smaller the receiver amplitude obtained. This result was found matched with the simulation using FEA. Figure 5 shows the sensor loss obtained when all the profiles were evaluated.

For a 7.7 mm profile, the receiving amplitude was zero because the profile size is larger than the transducer active diameter (7.1 mm) and all ultrasonic energy was reflected. Thus the sensor loss voltage is 3.64 V which is same as calibration voltage. On the other hand, for a 1.85 mm profile, the sensor loss measured was small because small ultrasonic energy was reflected at the gas surface (according to Equation 3). The result obtained using FEA also shows the similar trend.

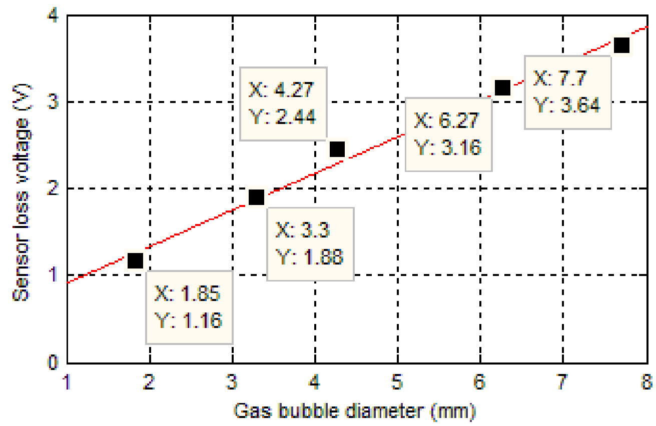



**Figure 5** The sensor loss voltage when several gas hold-up profiles were placed in the experimental column

The relationship between the sensor loss voltage, $V_G$ and the gas hold-up profiles can now be deduced. Using statistical software, the linear regression (red line) obtained is $y = 0.4217x + 0.4831$ with $R^2$ is 0.9887. Thus, the gas hold-up diameter, $G_D$ can be estimated using Equation (4):

$$G_D = \frac{V_C - V_R - 0.4831}{0.4217} \quad (4)$$

From the experiments, Equation (4) is valid for $G_D \geq 1.85$ mm or $ka \geq 3.87$ and up to 7.1 mm diameter (limited by the transducer diameter). The $R^2$ error could be improved if more measurement of samples were made. If smaller profiles were used (i.e. $ka$<<1), the amplitude of scattering has a strong dependence on the size of the profiles. Scattering in this case is approximately omni-directional and is known as Rayleigh scattering. Thus, the direction of scattering could not be identified. In some applications where smaller gas profiles are required, a higher ultrasonic frequency could be used.

## 4.0 CONCLUSIONS

The determination of gas hold-up profiles by means of ultrasonic transducer has been carried out. The basic fundamental of ultrasonic wave propagation has been discussed. Some mathematical studies to describe the gas hold-up parameter has been deduced. A finite element analysis was used to simulate the behaviour of ultrasonic wave upon gas hold-up obstacles and the simulation results were observed. The experimental setup for evaluating the gas hold-up profiles was constructed and the results were found to have similar agreement with the simulation. The gas hold-up diameter, $G_D$ were derived and can be estimated using Equation (4). The estimation for this equation is only valid for $G_D \geq 1.85$ mm and up to 7.1 mm diameter (limited by the transducer diameter).

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## References

[1] J. D. N. Cheeke. 2012. *Fundamentals and Applications of Ultrasonic Waves*. Boca Raton: CRC Press.

[2] J. A. Bamberger and M. S. Greenwood. 2004. Using Ultrasonic Attenuation to Monitor Slurry Mixing in Real Time. *Ultrasonics*. 42: 1–9, 145–148.

[3] M. H. F. Rahiman, R. A. Rahim, and Z. Zakaria. 2008. Design and Modelling of Ultrasonic Tomography for Two-component High-acoustic Impedance Mixture. *Sens. Actuators Phys.* 147(2): 409–414.

[4] N. M. Nor Ayob, M. J. Pusppanathan, R. Abdul Rahim, M. H. Fazalul Rahiman, and F. R. Mohd Yunus. 2013. Design Consideration for Front-End System in Ultrasonic Tomography. *J. Teknol.* 4(5): 53–58.

[5] C. M. Otto. 2012. *The Practice of Clinical Echocardiography*. Philadelphia, PA: Elsevier/Saunders.

[6] J. Xue, M. Al-Dahhan, M. P. Dudukovic, and R. F. Mudde. 2008. Bubble Velocity, Size, and Interfacial Area Measurements in a Bubble Column by Four-point Optical Probe. *AIChE J.* 54(2): 350–363.

[7] N. M. Nor Ayob, M. H. Fazalul Rahiman, Z. Zakaria, S. Yaacob, and R. Abdul Rahim. 2011. Simulative Study On Liquid/Gas Two–Phase Flow Measurement For Dual–Plane Ultrasonic Transmission–Mode Tomography. *J. Teknol.* 54(1): 79–94.